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Effects of Soil Type on Bermudagrass Response to Broiler Litter Application

A. Adeli,* D. E. Rowe, and J. J. Read

ABSTRACT

A greenhouse study was conducted to determine the effects of soil type on the response of 'Russell' bermudagrass [*Cynodon dactylon* (L.) Pers.] to broiler litter applications. Soils included Leeper clay loam (fine, smectitic, nonacid, thermic Vertic Epiaquept), Marietta silt loam (fine-silty, mixed, active, thermic Oxyaquic Fraglossudalf), and Ruston sandy loam (fine-loamy, siliceous, semiactive, thermic Typic Paleudult). The experimental design was a randomized complete block with a split plot arrangement of treatments replicated three times. Soil was used as main plot factor and broiler litter rates of 0, 4.6, 9.2, and 13.8 Mg ha^{-1} equivalent to approximately 0, 175, 350, and 525 kg total N ha^{-1} yr^{-1} were considered as subplot. The changes in dry matter yield (DMY) decreased in the order of Ruston > Leeper > Marietta. Regardless of soil type, broiler litter rates > 350 kg total N ha^{-1} did not increase DMY yield and nutrient uptake. Bermudagrass N concentration increased as broiler litter rate increased and the greatest value was recorded for Marietta soil, 24.2 g kg^{-1}. The large DMY observed in Ruston soil diluted plant N concentration to about 23.7 g kg^{-1} despite high percentage N recovery. Bermudagrass P concentration was not affected by either broiler litter rate or soil type. Bermudagrass K concentration increased as broiler litter rate increased and was greatest on Ruston soil (23.5 g kg^{-1}). Recovery efficiency for N and K was approximately 60% greater in Ruston than in Marietta and Leeper soils and was reflected in residual soil NO_3–N and P concentrations that decreased in the order of Marietta > Leeper > Ruston. Application of broiler litter to bermudagrass grown on the Ruston soil appears to be more sustainable.

A SUBSTANTIAL AMOUNT of broiler litter produced in the southeastern USA is typically applied to hay field and pastures close to the broiler houses (Bagley et al., 1996). The poultry industry in Mississippi generates approximately 1 million Mg yr^{-1} of poultry litter (MSES, 1998). Resource management legislation often emphasizes that land application of animal manure should not adversely affect the receiving environment. Of particular concern is the movement of N and P from land receiving animal manure application to the surface and ground waters, as this may degrade aquatic water systems (Bond, 1998; Cameron et al., 1997; Sharpley et al., 1993).

Hybrid bermudagrass is a tropical perennial grass that responds readily to applied fertilizer (Overman et al., 1993) and to intensive hay management (Overman et al., 1990). The effectiveness of this grass in nutrient utilization appears to be greater than other warm-season grasses. McLaughlin et al. (2004), comparing six warm-season perennial grasses on a Brooksville silty clay soil in Mississippi in a field receiving swine effluent reported bermudagrass DMY and nutrient removal exceeded those of the five other grasses by about 80%. Approximately half of the entire permanent pasture land area in Mississippi (1.08 million ha, 2.7 million acres) is devoted to bermudagrass. Most of the bermudagrass is in the south central part of the state, where 60% of the total broiler litter is produced (MSES, 1998). Used primarily for hay production and grazing, bermudagrass has considerable yield and nutrient uptake variation among different production areas, quite possibly due to differences in the wide range of soils and soil properties encountered in Mississippi.

Reduced forage yields and nutrient utilization in some soils can limit the benefit of bermudagrass for livestock producers. Nitrogen and P comprise the most agronomically and environmentally important proportions of the broiler litter (Sharpley et al., 1993). Because of the great response of bermudagrass to N, knowledge of the factors that affect the utilization and recovery of available nutrients in broiler litter applied to forages are needed for farmers and producers to estimate adequate application rates, to document accountability, and to use manure resources optimally (Cabrera and Gordillo, 1995). Traditionally, animal manure application rates are based on crop yield goals and knowledge of crop N utilization from the manure during the growing season (Sharpley et al., 1994). Sims (1986) reported the greatest percentage of N in poultry manure is in the organic fraction. Additionally, 20 to 40% of the total N in poultry litter has been reported to be in the inorganic form (Sims, 1986; 1987). Due to this fact, an estimate of the recovery of this N fraction is needed in widely contrasting soils.

Although the influence of broiler litter on the yield and nutrient removal of cool- and warm-season grasses is well documented (Kingery et al., 1993; Brink et al., 2002; Pederson et al., 2002), we know much less about the impact of soil type. Knowledge of the influence of soils on the utilization and recovery of nutrients, especially N and P, clearly affects the sustainability of agriculture management systems. The effectiveness of soil–plant systems to assimilate wastewater applied N and P depend on the biological, chemical, and physical attributes of the soil as well as plant uptake (Barton et al., 2005). Applied N from animal manure can be removed biologically via plant uptake (Adeli and Varco, 2002; Kingery et al., 1994), converted into organic matter via immobilization (Vuorinen and Saharinen, 1998) or lost through denitrification (Barton et al., 1999) and volatilization, especially in soils with an alkaline pH (Hoff et al., 1981). The amount of plant-available NH_4^+

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Abbreviations: DMY, dry matter yield; ICP, inductively coupled argon plasma emission spectrophotometer; PAN, plant-available nitrogen; TN, total nitrogen.

released from broiler litter to the soil may decrease by certain chemical processes, such as NH_4^+ fixation by surface soil or clays (Juang et al., 2001) and exchange NH_4^+ reaction with other cations such as K^+ in the soil (Chappell and Evangelon, 2000). In addition, when broiler litter is applied to meet plant N requirement there is potential for P build up in the soil (Sharpley et al., 1998). The effect of excess soil P on water quality is becoming a major concern (Sharpley et al., 1998). Applied P can be also chemically adsorbed by the soil or leached from the soil profile (Eghball, 2003; Barton et al., 2005).

It appears that the extent of all these biological and chemical processes will vary with soil type. For example, denitrification is often greater in loamy-textured as compared to sandy-textured soils (Barton et al., 1999), while P retention increases with increasing iron-oxides, aluminium oxides, and aluminosilicate minerals (Brennan et al., 1994). Denitrification coefficients range from 5% loss in well-drained soils to 50% loss in poor drainage conditions (Barton et al., 2005). Results from limited incubation studies to determine the effect of soil type on N mineralization found the amount of released N from the poultry manure was consistently greater in fine sand than in either loam or silty clay loam soils (Castellanos and Pratt, 1981; Chescheir et al., 1985; Chae and Tabatabai, 1986; Westerman et al., 1988).

Several studies have shown that chemical composition of poultry manure can affect the availability of nutrients in the manure for crop utilization (Bitzer and Sims, 1988; Serna and Pomares, 1991; Gordillo and Cabrera, 1997). However, few studies have determined quantitatively the effect of soil type on plant utilization, recovery, and assimilation of released nutrients from broiler litter into the soil. Soils vary in their chemical, biological, and physical properties and can therefore be expected to vary in their ability to assimilate animal manure nutrients. Previous research has shown geographic location and soil parent material were significant factors that contribute to nutrient uptake by forages with manure or commercial fertilizer (Stout et al., 1977).

One of the greatest challenges in pasture management is meeting nutrient requirements of the ruminant due to variable forage quality (Soder and Stout, 2003). Forage nutrient concentration can have a significant effect on animal performance and health as they are often not in balance with the nutrient requirement of the animals (Grunes and Welch, 1989). Research has shown that nutrient content and biomass production of forages are affected by fertilizer and manure applications (Van Horn et al., 1996; Gordillo and Cabrera, 1997; Bitzer and Sims, 1988). However, little work has linked the effects of soil type along with broiler litter applications on bermudagrass nutrient concentrations and DMY. In boiler litter management practices, choosing soil types that maximize plant growth and nutrient removal and minimize soil nutrient accumulation can be agronomically and environmentally beneficial. Since none of these soils collected from the bermudagrass production areas had received broiler litter, it is advantageous to evaluate the ability of soils in broiler litter–derived nutrient assimilation. The objective of our study was to determine if the response of bermudagrass to broiler litter application differs among contrasting soils.

MATERIALS AND METHODS

A greenhouse study was conducted at the Waste Management and Forage Research Unit (USDA-ARS) at Mississippi State, MS. Broiler litter was applied to 'Russel' bermudagrass grown in three widely differing soils. Bermudagrass was established by sprigging in a poorly drained Leeper clay loam formed in clayey alluvium on a flood plain; a moderately well-drained Marrietta silt loam formed in mixed loamy alluvium; and a well-drained Ruston sandy loam formed in friable coastal plain materials. Four grass sprigs were planted in each pot. These three dominant soils were selected from the bermudagrass production sites on the basis of wide differences in physical and chemical characteristics with the aid of the Mississippi Cooperative Extension Service. Broiler litter was collected from a poultry broiler house located at Plant Science Center (South Farm) at Mississippi State University. The initial physical and chemical characteristics of soils and chemical properties of broiler litter are shown in Table 1.

Soil and broiler litter pH were determined in water using a glass electrode and 1:2.5 soil/water ratio (Hanna pH/EC/TDS meter model H19813-0, Woonsocket, RI). Soil organic matter was calculated from total C (percentage of organic matter = total C × 1.72). Total C and N for soil and broiler litter were determined from air-dried, finely ground soil and litter using an automated dry combustion C/N analyzer (Model NA 1500 NC, Carlo Erba, Milan, Italy). Initial soil bulk density was determined for the samples taken from the soil surface in the field (undisturbed soil) using the oven-dried weight (105°C). Soil texture was determined by the method of Day (1965). Saturated hydraulic conductivity was determined using the method of Klute and Dirksen (1986). Denitrification enzyme activity was determined using the method of Smith and Tiedje (1979).

A total of 45 pots (18 cm wide by 20 cm deep filled with 6.5 kg air-dried soil) were used and placed on a greenhouse bench. A plastic tray was placed under each pot to collect possible leached water. Soils were repacked into the pots to

Table 1. Initial soil chemical and physical properties at 0- to 15-cm depth and broiler litter characteristics used in greenhouse study at USDA-ARS, Waste Management Unit, Mississippi State.

Parameter	Soil (0–15 cm)			Broiler litter
	Leeper	Marrietta	Ruston	
pH	8.2	5.2	6.7	7.4
Organic matter, g kg^{-1}	26.5	14.2	8.9	
Total N, %	0.19	0.05	0.09	3.85
Total P, g kg^{-1}	0.32	0.38	0.23	17.2
Mehlich-3 P, mg kg^{-1}	51.0	79.0	34.0	–
K, g kg^{-1}	0.168	0.196	0.45	31.2
Ca, g kg^{-1}	0.113	0.033	0.065	13.8
Mg, g kg^{-1}	–	–	–	6.9
C, g kg^{-1}	–	–	–	308.0
C/N ratio	–	–	–	8.0
N/P ratio	–	–	–	2.2
NH_4–N, mg kg^{-1}	27.6	5.4	22.6	6552.0
NO_3–N, mg kg^{-1}	22.4	20.1	18.6	16.0
K_w, mm h^{-1}†	20.0	30	340	–
DEA, μg N g^{-1} h^{-1}‡	45.0	28	0.6	–
Bulk density, g cm^{-3}	1.28	1.11	1.02	–
89Texture	clay loam	silt loam	sandy loam	–

† K_w, saturated hydraulic conductivity measured using the method of Klute and Dirksen (1986).

‡ DEA, denitrification enzyme activity measured using method of Smith and Tiedje (1979).

Table 2. Dry matter yield (DMY) and nutrient concentration of 'Alicia' bermudagrass grown in pots as influenced by soil type and broiler litter application rates.

Soil	DMY	N	P	K	Ca	Mg
	Mg ha^{-1} yr^{-1}	g kg^{-1}				
Ruston	6.8 a†	23.7 b	2.7 a	23.5 a	5.0 a	2.3 a
Leeper	3.4 b	21.4 c	2.2 b	22.1 b	5.2 a	2.2 a
Marrietta	2.6 c	24.2 a	2.1 b	22.2 b	5.2 a	2.3 a
LSD(0.05)	0.54	0.43	0.38	1.1	0.46	0.26
Broiler litter rate Mg ha^{-1}yr^{-1}						
0	2.4 c	13.5 d	2.3 a	20.1 d	5.8 a	2.6 a
4.6	4.3 b	23.3 b	2.4 a	22.0 c	5.2 b	2.3 a
9.2	5.3 a	25.9 a	2.4 a	23.5 b	4.8 c	2.1 a
13.8	4.9 b	22.0 b	2.3 a	24.7 a	4.5 c	2.0 a
CF‡	4.2 b	22.2 b	2.3 a	20.5 d	5.6 a	2.4 a
LSD(0.05)	0.32	2.2	0.21	0.97	0.33	0.52

† Within a column, means followed by a different letter differ at $P < 0.05$.
‡ Commercial fertilizer at the rate of 240 kg N and 79 kg P ha^{-1} yr^{-1}.

approximately the initial bulk density for the three soils. The experimental design was a randomized complete block with a split plot arrangement of treatments replicated three times. Soil was used as main plot factor and broiler litter rates of 0, 4.6, 9.2, and 13.8 Mg ha^{-1} equivalent to approximately 0, 175, 350, and 525 kg total N ha^{-1} yr^{-1} were considered as subplot. Since 68% of total broiler litter N is estimated as plant available in the first year of application (Bitzer and Sims, 1988), the calculated plant-available N (PAN) from broiler litter application was equivalent to 0, 120, 240, and 360 kg ha^{-1} yr^{-1}. These rates were applied to meet 0, 50, 100, and 150% of the annual bermudagrass N requirement of 240 kg N ha^{-1} yr^{-1}, as a recommended rate suggested by Martin et al. (1976). Plants were grown under nature light in the greenhouse. Temperature settings were 30°C daytime and 25°C nighttime.

Irrigation was applied when soil moisture reached 50% of field capacity (Tan, 1990). For each soil, a tensiometer was planted at the depth of 15 cm, major root zone, to estimate time of irrigation. Soil water tension at field capacity with no vegetation was 0.1, 0.3, and 0.4 bars for the Ruston sandy loam, Marrietta silt loam, and Leeper clay loam, respectively. Irrigation was applied when the pressure gauge of the tensiometer falls to about 0.4, 1.5, and 2 bars (equivalent to 50% available water remaining) for the Ruston, Marrietta, and Leeper soil, respectively. The aboveground biomass of bermudagrass was harvested by cutting with grass shears to a 5-cm stubble height when the sward height was approximately 30 cm on Day 28, 56, 84, and 112 after broiler litter application. Dry weight was determined after drying samples in a forced-air oven at 65°C for 5 d. For each harvest, dried plant materials were ground using a Wiley mill to pass a 1-mm sieve. Nitrogen concentration of bermudagrass was determined using an automated dry-combustion C/N analyzer.

For each harvest, forage P, K, Ca, and Mg concentrations were determined by dry-ashing 1-g samples in a ceramic crucible at 500°C for 4 h, dissolving the ash in acid (1 mL of 6 *M* HCl) for 1 h followed by addition of 40 mL of double acid (0.0125 *M* H_2SO_4 and 0.05 *M* HCl) for an additional hour, then filtering the extract through Whitman no. 1 filter paper. Phosphorus, K, Ca, and Mg concentrations of acid extracts were determined spectrophotometrically using inductively coupled argon plasma emission spectrophotometer (Thermo Jarrel Ash Iris Advantage ICP, 40669, Houghton, MI). Bermudagrass nutrient concentrations averaged over harvests and the means were reported in Table 2. Bermudagrass N and P uptake was calculated as the product of the plant nutrient concentration and DMY for each harvest. Apparent nutrient recovery in the harvested portion of plant is an important indicator of nutrient use efficiency and potentially reflects relative quantities of nutrients remaining in the soil. The apparent nutrient recovery was calculated as the quantity of the nutrient uptake from broiler litter–treated plots minus nutrient uptake from the untreated plot divided by the broiler litter nutrient application rates. There were no differences ($P <$ 0.05) among the harvests in terms of DMY and nutrient concentrations in each soil. Dry matter yield and nutrient uptake for each treatment were summed across harvests during the period of study.

Broiler litter P, K, Ca, and Mg concentrations were determined by dry-ashing procedure. A soil sample was taken at the end of the study, air-dried for 48 h, ground to pass a 2-mm sieve, extracted with 2 *M* KCl (Kenney and Nelson, 1982), and analyzed for inorganic N (NH_4^+ and NO_3^-) using Lachat instrument (QC 8000 flow injection analyzer, Loveland, CO). These samples were also extracted using Mehlich-3 extractant (Mehlich, 1984) and analyzed for plant-available P, K, Ca, and Mg using ICP. For each soil, grass roots were collected by washing out the soil particles, dried in a forced-air oven at 65°C for 5 d, and dry weight was recorded.

The General Linear Models (GLM) procedure in SAS (SAS Institute, 1990) was used to perform an analysis of variance and regression analysis of the data. Analysis of variance included main effects for soil type, broiler litter rate, the two-way interaction between soil type and fertilization level, and replication. The simple regression models included both linear and quadratic trends. Statistical differences of means were compared with Fisher's protected least significant difference (LSD) at probability level of $P < 0.05$.

RESULTS AND DISCUSSION

Dry Matter Yield

Because there was no soil type × broiler litter interaction ($P > 0.05$) for DMY; forage N, P, K, Ca, and Mg concentrations; and soil K, Ca, and Mg concentrations, data for these parameters are summarized over soils and broiler litter application treatments (Tables 2 and 3). Bermudagrass DMY increased ($P < 0.05$) with increasing broiler litter rates in the Ruston, Marietta, and Leeper soils (Fig. 1). In each soil, no difference in DMY was obtained between broiler litter and commercial fertilizer at equivalent rate of 240 kg PAN ha^{-1} (Fig. 1). Regression analyses showed quadratic trends in total DMY in all three soils. A similar trend was obtained for bermudagrass roots DM as compared with aboveground

Table 3. Post-harvest soil nutrient concentrations as influenced by soil type and broiler litter application to bermudagrass grown in pots.

Soil	K	Ca	Mg
	mg kg^{-1}		
Ruston	170 c†	1 187 c	173 a
Leeper	276 a	10 833 a	124 b
Marrietta	256 b	2 105 b	128 b
LSD(0.05)	14	268	23
Broiler litter rate Mg ha^{-1} yr^{-1}			
0	110 d	4 660 c	107 d
4.6	198 c	4 730 c	131 c
9.2	240 b	5 015 b	143 b
13.8	391 a	5 262 a	186 a
CF‡	205 c	4 755 c	142 b
LSD(0.05)	35	234	11

† Within a column, means followed by a different letter differ at $P < 0.05$.
‡ Commercial fertilizer at the rate of 240 kg N and 79 kg P ha^{-1} yr^{-1}.

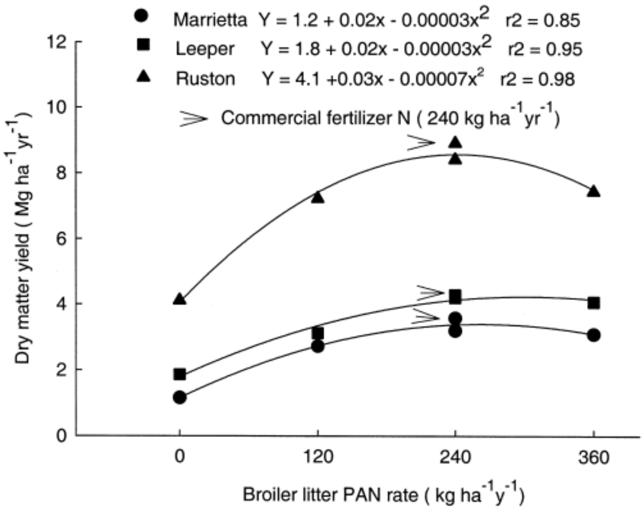

Fig. 1. Effects of broiler litter application rates on the aboveground biomass dry matter yield of bermudagrass grown in pots in three different soils.

biomass DMY. Bermudagrass roots DM increased quadratically ($P < 0.05$) with increasing broiler litter rates (Fig. 2). Maximum DM for roots were 6.3, 3.6, and 3.2 g plot^{-1} at the optimum broiler litter rate of 9.2 Mg ha^{-1} in Ruston, Leeper, and Marietta soils, respectively (Fig. 2). Regardless of soil type, it appears that N provided in broiler litter should not exceed approximately 350 kg total N ha^{-1} yr^{-1} (240 kg PAN ha^{-1} yr^{-1}) or 9.2 Mg broiler litter ha^{-1} yr^{-1}. Yield performance differed among soils, with average DMY of bermudagrass ranging from 2.6 Mg ha^{-1} in Marietta to 6.8 Mg ha^{-1} in the Ruston soil (Table 2). However, in all soils, the magnitude of bermudagrass DMY was much lower than that reported (12.5–16.5 Mg ha^{-1} yr^{-1}) by Brink et al. (2002) for bermudagrass fertilized with a loading rate of 9 Mg ha^{-1} yr^{-1} of broiler litter on a Savannah sandy loam soil. Broiler litter had the greatest effect on DMY in the Ruston soil and the changes in DMY decreased in the order of Ruston > Leeper > Marietta (Fig. 1).

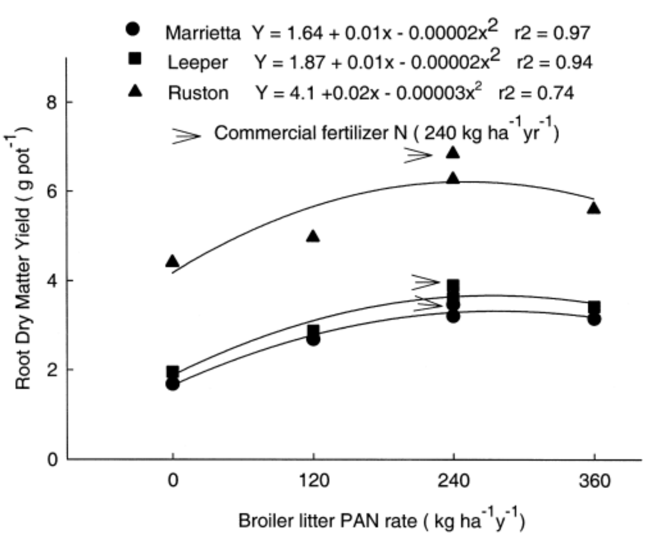

Fig. 2. Effects of broiler litter application rates on root dry matter yield of bermudagrass grown in pots in three different soils.

In a greenhouse study in which bermudagrass fertilized with beef cattle feedyard effluent in two widely different soil types, Miller et al. (2001) reported that DMY was greater in Pullman clay loam than in Amarillo fine sandy loam soil. In contrast to work by Miller et al. (2001), our results indicated bermudagrass DMY was greatest in Ruston sandy loam as compared with Leeper silty clay loam and Marietta silt loam. Lower DMY production in Leeper than Ruston soil could possibly be related to either increased NH_3 volatilization from the soil due to alkaline pH (Hoff et al., 1981) or probable NH_4^+ fixation by surface soil and clays as evidenced by low tissue N concentration and low residual soil NO_3^- at the end of the study (Table 2 and Fig. 5). It seems that as the limited adsorption sites in the Ruston sandy soil became saturated, released N from mineralization remained in solution and became available for plant use. In Marietta soil, the low response of bermudagrass to broiler litter could be related to an acidic pH below 5.5 (Table 1) possibly limiting root and shoot growth especially in newly sprigged plants (Eichhorn and Bell, 1993). Although animal manure application increases soil pH (Soder and Stout, 2003), broiler litter rates used in this study did not affect soil pH.

Tissue Nutrient Concentration

Averaged over soils, bermudagrass N concentration increased quadratically with increasing broiler litter rates ($P < 0.05$) (Table 2), indicating a decline in assimilation efficiency with excessive rate. Forage N concentration was greatest with 350 kg total N ha^{-1} yr^{-1} (240 kg PAN ha^{-1} yr^{-1}) or 9.2 Mg broiler litter ha^{-1} yr^{-1} ($P <$ 0.05) and lowest at the 0 kg N ha^{-1} ($P < 0.05$; Table 2). Bermudagrass N concentration decreased at a broiler litter rate greater than 9.2 Mg ha^{-1} yr^{-1} ($P < 0.05$). Averaged across broiler litter rates, bermudagrass N concentration was greatest on the Marietta soil (24.2 g kg^{-1}) and least N on the Leeper soil (21.4 g kg^{-1}) ($P <$ 0.05; Table 2). However, total DMY was greater in the Ruston than the Marietta soil ($P < 0.05$). This discrepancy is explained by the fact that greater yield in the Ruston soil diluted the plant N concentration.

To determine the nature of N accumulation response to broiler litter N, DMY of bermudagrass were regressed against N concentration in all three soils (Table 4). Regardless of soil type, changes in bermudagrass DMY across litter rates were related quadratically to tissue N concentration indicating N accumulation by bermudagrass. This response was a function of both tissue N concentrations and DMY. Maximum values for

Table 4. Bermudagrass yield dependency on tissue N and P concentrations in three soils treated with broiler litter.

	Yield vs. N conc.		Yield vs. P conc.	
Soil	Regression equation	R^2	Regression equation	R^2
Marrietta	$Y = -6.23 + 0.8x - 0.017x^2$	0.93**	NS	
Leeper	$Y = -39.7 + 4.0x - 0.091x^2$	0.96**	NS	
Ruston	$Y = -5.5 + 1.07x - 0.021x^2$	0.95**	NS	

** Significant at $P < 0.001$ probability level. NS, not significant.

bermudagrass DMY of 8.4, 4.3, and 3.2 Mg ha^{-1} was obtained with tissue N concentrations of approximately 26, 29, and 23 g kg^{-1} in Ruston, Marietta, and Leeper soils, respectively (data not shown). The low forage N concentration in Leeper clay soil could be related to less N available for plant utilization, which was probably caused by NH_3 volatilization in the Leeper soil due to an alkaline pH (Hoff et al., 1981) and ammonium fixation by surface soil and clays (Juang et al., 2001).

Increasing broiler litter rates did not increase P concentration in bermudagrass (Table 2). However, total P uptake increased quadratically with increased broiler litter applications (Fig. 4), a similar trend as in DMY (Fig. 1). When bermudagrass yields were regressed against P concentration in all three soils (Table 4), changes in DMY were not correlated with tissue P concentration. This suggests the quantity of P removed by harvested bermudagrass most likely depends on DMY rather than tissue P concentration. Averaged across broiler litter rates, no differences in P concentration were obtained among the soils ($P > 0.05$) (Table 2).

Bermudagrass K concentration increased with increasing broiler litter application rate ($P < 0.05$; Table 2), although all broiler litter rates brought bermudagrass K concentrations above the critical range of 2% (Martin and Matocha, 1973). This is because K can be utilized by plants in excess of that required for growth (Miller and Reetz, 1995). Bermudagrass K was greater in Ruston soil than in Leeper and Marietta soils. This was because at relatively low soil K concentrations in Ruston soil (Table 3), bermudagrass K utilization would be at a faster rate than in the other two soils.

In contrast to K, bermudagrass Ca and Mg concentrations decreased with increasing broiler litter application rates ($P < 0.05$; Table 2), whereas soil Ca and Mg concentration increased with broiler litter application rates ($P < 0.05$; Table 3). The decreasing bermudagrass Ca and Mg utilizations could be related to the large amount of K being applied in the broiler litter thereby decreasing the uptake of Ca and Mg by bermudagrass (Soder and Stout, 2003). The amount of broiler litter K was greater than the sum of broiler litter Ca and Mg (Table 1).

For all soils, the K/(Ca + Mg) ratio for 'Russel' bermudagrass was greater than the 2.2 threshold for grass tetany reported by Grunes and Welch (1989). Averaged across broiler litter application rates, this ratio was 3.4, 2.9, and 3.0 in the Ruston, Leeper, and Marrietta soils, respectively (data not shown). Although grass tetany is considered a grazing problem, the effects of feeding ruminant animals with high K/(Ca + Mg) ratio hay of bermudagrass are unknown. 'Russel' bermudagrass has not been linked with grass tetany in forage literature, but the potential for grass tetany problems from feeding this grass following heavy fertilization with broiler litter should be investigated.

Nutrient Uptake and Recovery

Total N accumulation by bermudagrass in the Ruston, Marrietta, and Leeper soil increased with increasing broiler litter application rates (Fig. 3). Due to greater DMY in the Ruston soil, N removal was around 60% greater than the other two soils at the optimum rate of broiler litter application (9.2 Mg ha^{-1} yr^{-1}). Regression analysis indicated quadratic trends in N uptake by bermudagrass in response to broiler litter rates (Fig. 3). Plant uptake of N decreased in the order of Ruston soil (220 kg N ha^{-1}) > Leeper soil (97 kg N ha^{-1}) > Marrietta soil (92 kg N ha^{-1}) at broiler litter of 9.2 Mg ha^{-1} yr^{-1} (350 kg N ha^{-1}).

Based on the assumption that 68% of total broiler litter N is plant available in the first year (Bitzer and Sims, 1988), total plant N uptake at the optimum rate of 350 kg total N ha^{-1} yr^{-1} (or 240 kg PAN ha^{-1} yr^{-1}) represented 92% of the plant-available N applied to Ruston soil, 41% of that applied to Leeper soil, and 39% of that applied to Marietta soil. Bermudagrass N uptake varied considerably between soils, ranging from 220 kg N ha^{-1} for Ruston and 92 kg N ha^{-1} for Marietta soil (Fig. 3). Lower plant N uptake from Leeper soil than Ruston soil could be possibly related to greater NH_3 volatilization from Leeper soil with alkaline pH (Hoff et al., 1981) or NH_4 fixation by the soil surface and clay minerals (Juang et al., 2001). Lower plant N uptake from Marietta than Ruston is possibly related to the slightly acidic pH (Table 1), which may have limited plant N uptake in this soil by reducing root and shoot growth. Total K, Ca, and Mg removal by bermudagrass increased quadratically with increasing broiler litter applications to the Ruston, Marrietta, and Leeper soils (Table 5). The magnitude of K, Ca, and Mg uptake by bermudagrass was much greater in Ruston compared with the other soils.

For all soils, apparent N recovery tended to decrease with increasing broiler litter application rates (Table 6). Averaged across the broiler litter rates, apparent N recovery rates for bermudagrass in the Ruston soil were 62 and 54% greater than in the Marietta and Leeper soils, respectively. Potassium recovery was about 60% greater in the Ruston soil than the other two soils.

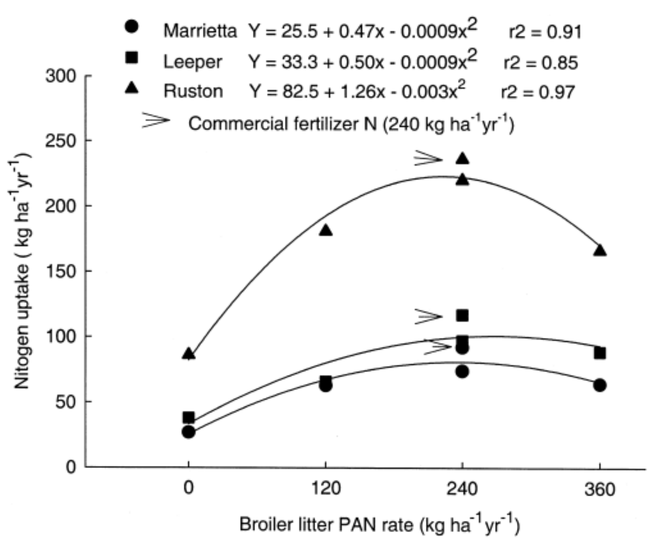

Fig. 3. Effects of broiler litter application rates on the N uptake by bermudagrass grown in pots in three different soils.

Table 5. Effects of broiler litter rates on K, Ca, and Mg uptake by bermudagrass grown in pots in three soils.

	Soil								
	Leeper			Marrietta			Ruston		
Broiler litter rate	K	Ca	Mg	K	Ca	Mg	K	Ca	Mg
$Mg\ ha^{-1}yr^{-1}$	$kg\ ha^{-1}\ yr^{-1}$								
0	39	11	4	25	6	3	73	25	12
4.6	68	16	7	59	14	6	160	38	17
9.2	96	22	9	72	16	7	216	39	18
13.8	95	20	8	71	15	7	209	30	14
Regression									
Broiler litter linear	NS	NS	NS	NS	NS	NS	NS	NS	NS
Broiler litter quadratic	*	**	*	**	*	NS	**	**	**

* Significant at $P < 0.05$ probability level. NS, not significant.
** Significant at $P < 0.001$ probability level.

Higher N and K recovery rates in the Ruston soil appears to be primarily related to increased dry matter accumulation.

For all soils, P removal by bermudagrass increased with increasing broiler litter application rate (Fig. 4). Due to greater DMY in the Ruston soil, P uptake by bermudagrass in the Ruston was 63 and 73% greater than Leeper and Marietta soils at the optimum rate of broiler litter application (9.2 Mg ha^{-1} yr^{-1} or 158 kg P ha^{-1} yr^{-1}) (Fig. 4). Regression analysis indicated quadratic trend in bermudagrass P uptake across broiler litter rates. Similar to plant N uptake, total P uptake decreased in the order of Ruston (25 kg P ha^{-1} yr^{-1}) > Leeper (9.4 kg P ha^{-1} yr^{-1}) > Marietta (6.7 kg P ha^{-1} yr^{-1}) with application of broiler litter at the rate of 9.2 Mg ha^{-1} yr^{-1} (158 kg P ha^{-1} yr^{-1}). Total P uptake, as a percentage of broiler litter applied, was less than that of N, and represented 16% of the applied P to the Ruston soil, 6% of that applied to the Leeper soil, and 4% of that applied to the Marietta soil. The lower magnitude of bermudagrass P recovery for Marietta and Leeper soils as compared with the Ruston soil, suggests more P would remain in these soils at similar rates of broiler litter.

Residual Soil Nitrate-Nitrogen Concentration and Soil Phosphorus Concentration

Residual soil NO_3–N concentration increased at the highest broiler litter rate of 13.8 Mg ha^{-1} yr^{-1} (525 kg total N ha^{-1} yr^{-1}) with concentrations of 56, 17, and 30 mg kg^{-1} observed in Marietta, Leeper, and Ruston soil, respectively. The lowest NO_3–N concentration in Leeper could be related to N loss as evidenced by low N

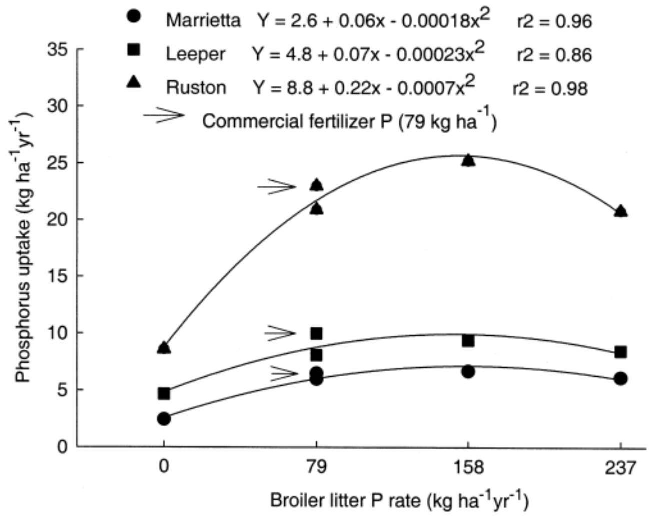

Fig. 4. Effects of broiler litter application rates on the P uptake by bermudagrass grown in pots in three different soils.

accumulation and recovery by bermudagrass at broiler litter rate of 13.8 Mg ha^{-1} yr^{-1}. Residual NO_3–N was greatest the Marietta soil, which could be related the very low DMY and N removal from this soil. Although N was available in Marietta soil, plants did not use it effectively, which may have been related to acidic pH (Table 1) limiting root and shoot growth.

Broiler litter at low, medium, and high rates resulted in P applications of 79, 158, and 237 kg ha^{-1} yr^{-1} to each of Ruston, Leeper, and Marietta soils (Table 7). Due to low DMY and very low P recovery by bermudagrass in the Leeper and Marietta soils, soil Mehlich-3 P concentration increased with increasing broiler litter rate (Fig. 5). Soil P concentration was much lower in the Ruston soil as evidenced by approximately 50% greater P recovery in this soil as compared with the Marrietta and Leeper soils.

Nitrogen/Phosphorus Accumulation Ratios

The narrowest N/P uptake ratios for the bermudagrass were 9.5, 9.0, and 9.3 for the untreated checks in the Ruston, Leeper, and Marietta soils, respectively. Averaged across broiler litter rates, the uptake ratios for bermudagrass increased from 9.0 to 9.6 in Leeper and from 9.3 to 11.3 in Marietta soil. But in Ruston soil, the bermudagrass N/P uptake ratio decreased from 9.5 in untreated soil to 8.4 in manured soil (Table 8). An increase in the uptake ratio with broiler litter compared with untreated check in Leeper and Marietta soils suggests N was the more limiting of the two nutrients and

Table 6. Effects of broiler litter application rates on N, P, and K recovery by bermudagrass grown in pots in three soils.

	Soil								
	Marrietta			Leeper			Ruston		
Broiler litter rate	N	P	K	N	P	K	N	P	K
$Mg\ ha^{-1}yr^{-1}$	% recovery								
4.6	21	6	24	16	6	20	54	9	60
9.2	19	4	16	17	3	20	38	8	50
13.8	7	2.	11	10	2	13	15	5	31
Regression									
Broiler litter linear	**	**	**	**	**	NS	**	**	**

** Significant at $P < 0.001$ probability level. NS, not significant.

Table 7. Nutrient rates applied to bermudagrass grown on Leeper, Marrietta, and Ruston soils treated with broiler litter.

Broiler litter rate	TN†	PAN‡	P	K	Ca	Mg
$Mg\ ha^{-1}yr^{-1}$	$kg\ ha^{-1}$					
4.6	175	120	78	144	63	32
9.2	350	240	156	288	126	64
13.8	525	360	234	432	189	96

† TN, total N applied.
‡ PAN, plant-available N.

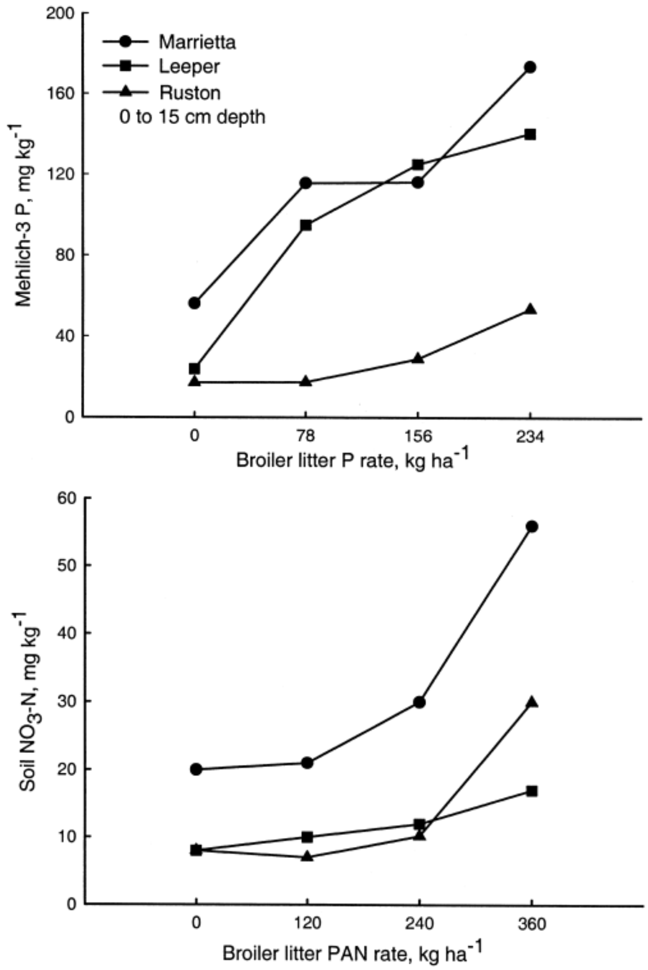

Fig. 5. Effects of broiler litter application rates on residual soil NO_3–N and soil P concentration in three different soils.

soil accumulation of P would be expected. However, soil P accumulation is expected to be much smaller in Ruston than the Marietta and Leeper soils (Fig. 5) as evidenced by a smaller bermudagrass N/P uptake ratio in this soil. When the objective in such a system is to provide adequate N for optimum bermudagrass production, while avoiding accumulation of excess P in the soil, bermudagrass with an uptake ratio <10 in the Ruston soil is expected to satisfy the objective.

CONCLUSIONS

For all soils, broiler litter application rates >9.2 Mg ha^{-1} yr^{-1} or 350 kg N ha^{-1} yr^{-1} (240 kg PAN ha^{-1} yr^{-1}) did not increase dry matter yield and was in excess of bermudagrass N utilization potential. This was evident from decrease nutrient recovery and increased residual soil NO_3–N and P concentrations at 13.8 Mg ha^{-1} yr^{-1}. Response of bermudagrass to broiler litter was much greater in the Ruston soil than either Leeper or Marietta soils. It seems that the limited adsorption sites in Ruston sandy loam soil became saturated, and N and P released from broiler litter during mineralization was more concentrated in soil solution and may have contributed to enhanced nutrient uptake. The results of this study indicated that there was significant variability in nutrient concentrations based on soil type and broiler litter rates. Because nutrient concentrations in soils and forages are useful in developing baseline recommendations for broiler litter applications in different locations and soils, more research in the field is needed to determine the fate of the broiler litter derived nutrients in these soils. Comprehensive forage and soil testing based on individual farm situation could be the best strategy for broiler litter management practices in the region and to ensure proper mineral nutrition in forages or pastures for ruminant animals.

Table 8. Effects of broiler litter rates on N/P uptake ratio of bermudagrass grown in pots in three soils.

	Soil		
Broiler litter rate	Leeper	Marrietta	Ruston
Mg ha^{-1}yr^{-1}		N/P ratio	
0	9.0	9.3	9.5
4.6	8.1	9.7	8.7
9.2	10.3	13.7	8.8
13.8	10.4	10.4	7.9
LSD(0.05)	0.57	0.66	0.32

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